Entergy

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Christina Perino
Licensing Manager

GNRO-2012/00109

September 6, 2012

U.S. Nuclear Regulatory Commission (NRC)
Attn: Document Control Desk
Washington, D.C. 20555

Subject: Grand Gulf Nuclear Station Stress Analysis Summary Demonstrating that the Nozzle to Safe-End DMW, N06B-KB, Will Perform its Intended Design Function After Weld Overlay Installation
Grand Gulf Nuclear Station (GGNS), Unit 1
Docket No. 50-416
License No. NPF-29

Reference: Grand Gulf Nuclear Station Relief Request ISI-17 Repair Plan for ISI Weld N06B-KB, dated May 2, 2012, (GNRO-2012/00040; ADAMS Accession No. ML12124A245)

Dear Sir or Madam:

In a letter dated May 2, 2012, Grand Gulf Nuclear Station (GGNS) requested approval of Relief Request ISI-17 to repair degraded weld N06B-KB at the "C" nozzle in the Residual Heat Removal (RHR) / Low Pressure Core Injection (LPCI) system. In the referenced relief request, GGNS committed to providing a summary of the stress analysis demonstrating that the nozzle to safe-end DMW, N06B-KB, will perform its intended design function after weld overlay installation within 90 days of completing refueling outage 18. The Attachment contains the Stress Analysis Summary for the Weld Overlay Repair of the RHR/LPCI Nozzle-to-Safe End DMW, N06B-KB.

This letter contains no new commitments. If you have questions or require additional information concerning this report, please contact Ernest Rufus at (601) 437-6582.

Sincerely,

Rita R. Jackson for C. Perino

CLP\jas

Attachment: Stress Analysis Summary for the Weld Overlay Repair of the RHR/LPCI Nozzle-to-Safe End DMW, N06B-KB

cc: (see next page)

cc With Attachment:

NRC Senior Resident Inspector
Grand Gulf Nuclear Station
Port Gibson, MS 39150

U.S. Nuclear Regulatory Commission
ATTN: Mr. Elmo E. Collins, Jr.
Region Administrator, Region IV
1600 East Lamar Boulevard
Arlington, TX 76011-4511

U. S. Nuclear Regulatory Commission
ATTN: Mr. Alan Wang, NRR/DORL
Mail Stop OWFN/8 B1
Washington, DC 20555-0001

Attachment to

GNRO-2012/00109

Stress Analysis Summary for the Weld Overlay Repair of the RHR/LPCI Nozzle-to-Safe End DMW, N06B-KB

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August 24, 2012
Report No. 1200536.403.R0
Quality Program: ☒ Nuclear ☐ Commercial

Mr. Robert W. Fuller
Grand Gulf Nuclear Station – Entergy
7003 Bald Hill Road
Port Gibson, MS 39150

Subject: Summary of Design and Analyses of Weld Overlay Repair for the Grand Gulf Nuclear Station Residual Heat Removal (RHR)/Low Pressure Coolant Injection (LPCI) "C" Nozzle-to-Safe End Dissimilar Metal Weld (DMW), N06B-KB

Reference: Entergy Operations, Inc. Grand Gulf Nuclear Station (GGNS) Relief Request ISI-17 Repair Plan for ISI Weld N06B-KB

Dear Mr. Fuller:

The following attachment is transmitted in support of Entergy's commitment in the above-referenced relief request:

Attachment: Stress analysis summary demonstrating that the nozzle-to-safe end DMW, N06B-KB, will perform its intended design function after weld overlay installation.

If you have any questions or comments regarding this summary, please contact one of the undersigned.

Prepared by:

Moses Taylor, Jr., P.E.
Senior Associate

8/24/2012
Date

Verified by:

Richard L. Bax
Associate

8/24/2012
Date

Approved by:

Moses Taylor, Jr., P.E.
Senior Associate

8/24/12
Date

Attachment

cc: Project File No. 1200536.403 (Entergy Operations, Inc. Purchase Order No. 10324360)

Attachment

Stress Analysis Summary for the Weld Overlay Repair of the RHR/LPCI Nozzle-to-Safe End DMW, N06B-KB

1.0 Introduction

An axial flaw indication was identified in the Grand Gulf Nuclear Station (GGNS) Residual Heat Removal (RHR)/Low Pressure Coolant Injection (LPCI) Loop "C" N06-KB (N-6) nozzle-to-safe end dissimilar metal weld (DMW) during nondestructive examination in Spring 2012 [1]. The nozzle weld/butter material is Alloy 82/182, which is known to be susceptible to intergranular stress corrosion cracking (IGSCC). The decision was made by Entergy Operations, Inc. (Entergy) to repair this location using a full structural weld overlay (WOL) to eliminate dependence upon the Alloy 82/182 weld as a pressure boundary weld, and to mitigate any potential for IGSCC in this weld in the future. The WOL was installed during the Spring 2012 outage using a IGSCC resistant weld filler material, Alloy 52M [4].

The requirements for design of weld overlay repairs are defined in the Relief Request [1], which is based upon ASME Code Cases N-504-4 [2] and N-638-4 [3], and ASME Code, Section XI, Nonmandatory Appendix Q [5]. The analytical basis for the design of the repairs is in accordance with the requirements of ASME Code, Section XI [6], IWB-3641. Weld overlay repairs are considered to be acceptable long-term repairs for IGSCC-flawed weldments if they meet a conservative set of design assumptions, which qualify them as "full structural" weld overlays. The three principal design requirements that qualify a weld overlay as "full structural" are as follows:

1. The design basis for the repair is a circumferentially oriented flaw that extends 360° around the component, and is 100% through the original component wall. This conservative assumption eliminates concerns about IGSCC susceptibility of the original Alloy 82/182 DMW. In addition, potential concerns about the integrity of the original butt weld material are not applicable, since no credit is taken in the design process for the load carrying capability of this weld.

2. As required by ASME Code, Section XI [6], IWB-3641, a combination of internal pressure, deadweight, seismic, and other dynamic stresses is used in the design of a weld overlay repair. Thermal and other secondary stresses are not required to be included for structural sizing calculations (since the repairs are applied using a GTAW process that produces a high toughness weld deposit), but they are addressed later in subsequent stress, fatigue, and stress corrosion cracking evaluations.

3. Following the repair, the surface finish of the overlay must be sufficiently smooth to allow preservice and future inservice ultrasonic examinations through the overlay material and into a portion of the original base metal. The purpose of these examinations is to demonstrate that the overlay design basis does not degrade with time due to flaw propagation.

ASME Code, Section III stress and fatigue usage evaluations are also performed to demonstrate that the overlaid components continue to meet ASME Code, Section III requirements. The original construction Code for the RHR/LPCI Loop "C" nozzle was ASME, Section III, 1971 Edition, Winter 1972 Addenda [8]. However, as allowed by ASME Code, Section XI [6], Code Editions and Addenda later than the original construction Code may be used. ASME Code, Section III, 2001 Edition with Addenda through 2003 [7] was used for these analyses.

In addition to providing structural reinforcement to the IGSCC susceptible locations with a resistant material, weld overlays have also been shown to produce beneficial residual stresses that mitigate IGSCC in the underlying DMWs. The weld overlay approach has been used to repair stress corrosion cracking in U.S. nuclear plants on hundreds of welds, and there have been no reports of subsequent crack extension after application of weld overlays. Thus, the compressive stresses caused by the weld overlay have been effective in mitigating new crack initiation and/or growth of existing cracks.

Finally, evaluations are performed, based on as-built measurements taken after the overlays are applied, to demonstrate that the overlays meet their design basis requirements, and that they will not have an adverse effect on the balance of the piping systems. These include comparison of overlay dimensions to design dimensions, evaluations of shrinkage stresses and added weight effects on the piping systems.

2.0 Analysis Summary and Results

2.1 Weld Overlay Structural Sizing Calculations

ASME Code Case N-504-4 [2], which incorporates ASME Code, Section XI [6], IWB-3640 evaluation methodology, was used to determine the thickness of the overlay. Equations from ASME Code, Section XI [6], Appendix C, and the maximum stresses at the nozzle for any Service Level, were used to determine the design WOL thickness. The resulting minimum required overlay thickness is summarized in Table 2-1.

The weld overlay length must consider three requirements: (1) length required for structural reinforcement, (2) length required for access for preservice and inservice examinations of the overlaid weld, and (3) limitation on the area of the nozzle that can be overlaid.

In accordance with the Relief Request [1], which is based on ASME Code Cases N-504-4 [2], the minimum weld overlay length required for structural reinforcement is the length which will provide adequate load transfer from one side of the flaw to the other. Per Reference [2], this criteria is generally satisfied if the overlay full thickness length extends axially at least $0.75\sqrt{Rt}$ on each side of susceptible material where R and t are the outer radius and nominal wall thickness of the overlaid components, prior to depositing the weld overlay, and the end slope is no steeper than 45°.

The resulting minimum length requirements are summarized in Table 2-1. Note that these length dimensions are measured from the intersection of the original DMW construction weld with the safe end and from the intersection of the original nozzle dissimilar metal weld with the nozzle material on the outside surface of the nozzle. An illustration of the weld overlay design is provided in Figure 2-1.

WOL access for preservice examination requires that the overlay length and profile be such that the required post-WOL examination volume can be inspected using the PDI qualified non-destructive examination (NDE) techniques. This requirement could cause the overlay length and thickness to be longer than required for structural reinforcement. The amount of any required additional thickness and length is determined by Entergy and the qualified NDE personnel.

ASME Code Case N-638-4 [3] limits the area of the N-6 nozzle covered by the WOL to below the 500 square inches.

The as-built weld overlay thickness and length are provided in Table 2-2. These measurements exceed the minimum required structural design dimensions shown in Table 2-1, thereby demonstrating the adequacy of the as-installed repair.

2.2 Section III Stress Analyses

Stress intensities for the weld overlaid RHR/LPCI nozzle-to-safe end DMW were determined from finite element analyses for the various specified load combinations and transients. Linearized stresses were evaluated at six stress locations using a 3-dimensional finite element model. The finite element model showing stress path locations is provided in Figure 2-2.

Paths 1 to 4 are located at sections near the toe of the weld overlay. Paths 6 and 9 are in the middle of the DMW. The remaining paths shown in Figure 2-2 are used to support the crack growth evaluation discussed in Section 2.3 below. The stress intensities at these locations were evaluated in accordance with ASME Code, Section III [7], Sub-article NB-3200, and compared to applicable Code limits. A summary of the stress and fatigue usage comparisons for the evaluated path locations is provided in Table 2-3 through Table 2-9. The stresses and fatigue usage in the weld overlaid nozzle are within the applicable Code limits.

2.3 Residual Stress and ASME Code, Section XI Crack Growth Analyses

Weld residual stresses for the N06B-KB DMW overlay were determined by detailed elastic-plastic finite element analyses. The analysis approach has been previously documented to provide predictions of weld residual stresses that are in reasonable agreement with experimental measurements. A two-dimensional, axisymmetric finite element model was developed for the N-6 nozzle. Modeling of weld nuggets used in the analysis to lump the combined effects of several weld beads is illustrated in Figure 2-3. The model simulated an inside surface (ID) repair at the nozzle-to-safe end DMW location with a depth of approximately 50% of the original wall thickness. This assumption is considered to conservatively bound any weld repairs that may have been performed during plant construction from the standpoint of producing tensile residual stresses on the ID of the weld.

The residual stress analysis approach consists of a thermal pass to determine the temperature response of the model to each individual lumped weld nugget as it is added in sequence, followed by an elastic-plastic stress pass to calculate the residual stresses due to the temperature cycling from the application of each nugget. Since residual stresses are a function of welding history, the stress passes for each nugget are performed sequentially, over the residual stress fields induced from all previously applied weld nuggets. The resulting residual stresses were evaluated on the inside surface of the original weld and safe-end, as well as on several paths through the DMW as shown in the finite element model, Figure 2-2 (Paths 5 through10). Residual stress plots are shown in Figures 2-4 and 2-5. Note that the IGSCC susceptible DMW regions are marked by bold vertical lines in these figures.

The residual stress calculations were then utilized, along with stresses due to applied loadings and thermal transients, to demonstrate that the as-found axial flaw and an assumed 75% through-wall circumferential flaw will not grow beyond the design basis for the weld overlay for the time period until the next scheduled inservice or other scheduled inspection due to fatigue or IGSCC (or both). In the fatigue crack growth analyses, the 40 year design cycles for each applied transient were assumed. The design basis flaw for crack growth purposes is the original weld thickness. In this evaluation, the results in Table 2-10 show that in the susceptible DMW material region, it takes greater than 40 years for the initial as-found axial flaw (0.5 inch) and a postulated initial circumferential flaw of 75% of the original base metal thickness (1.03 inches) at the analyzed section to reach the overlay.

The analysis also considered IGSCC in the DMW and showed that the stress intensity factors for sustained loads at normal steady state operating conditions were negative at the initial flaw depths and through the remaining ligament of the original DMW thickness. Therefore, the WOL effectively eliminates the potential for IGSCC growth for the as-found axial and postulated circumferential flaws by generating favorable residual stresses in the DMW.

2.4 Evaluation of Weld Overlay Effects on Piping System

The weld overlay shrinkages were measured at four azimuthal locations around the nozzle following the repair and the maximum measured axial shrinkage was 0.08 inch for the N-6 nozzle. Although there are no acceptance criteria for axial shrinkage stresses in the ASME Code, the maximum measured axial shrinkage was included in a piping analysis model of the system and the resulting stresses were compared to the cold spring allowable stress in the ASME Code. The maximum computed shrinkage stress was small (less than 4%) compared to the Code allowable.

All hangers, supports, and restraints that may be potentially affected were checked by Entergy personnel after the application of the overlay repair, and they were all found to be acceptable. Thus, the observed shrinkage levels are deemed to be acceptable.

The N-6 nozzle weld overlay covers only a portion of the N-6 nozzle and the adjacent safe end. It does not extend onto the piping which starts at the safe end-to-pipe weld. Accordingly, the weld overlay of the N-6 nozzle does not affect the weight of the piping system.

Table 2-1: Weld Overlay Minimum Structural Thickness and Length Requirements

Item	Location	Thickness or Length
Minimum Thickness (in.)	Nozzle Side	0.48
	Safe End Side	0.48
Minimum** Length (in.)	Nozzle Side	NA*
	Safe End Side	2.3

Notes:

* WOL only required to blend into nozzle radius.

** Length shown is the minimum required for structural acceptance and does not include any additional length necessary to meet inspectability requirements.

Table 2-2: Post-Weld Overlay As-Built Dimensions

Item	Location	Thickness or Length
Minimum Measured Thickness (in.)	Nozzle Side*	0.84
	Safe End Side**	0.97
Minimum Measured Length (in.)	Nozzle Side	2.57
	Safe End Side	2.49

Notes:

* Measurement taken on nozzle side of nozzle-to-safe end weld.

** Measurement taken on safe end side of nozzle-to-safe end weld.

Table 2-3: Design Code Evaluation

		Path 1	Path 2	Path 3	Path 4	Path 6	Path 9
P_m / P_L (3)	Press (2)	5.743	2.925	4.573	5.496	3.386	3.224
	DW	2.912	1.299	2.890	1.274	1.761	1.705
	OBE RFE	4.860	2.184	4.812	2.130	2.955	2.833
	Sleeve Load	0.667	0.316	0.646	0.292	0.436	0.383
	P+DW+OBE	**14.183**	**6.723**	**12.920**	**9.192**	**8.539**	**8.145**
	Allowable (3,4) (1.0 S_m)	**23.3**	**23.3**	**23.3**	**23.3**	**23.3**	**23.3**
P_L+P_b (Inside)	Press (2)	7.830	6.053	4.833	7.976	4.978	3.096
	DW	3.060	0.620	3.042	0.732	1.814	1.730
	OBE RFE	5.120	1.061	5.082	1.302	3.088	2.907
	Sleeve Load	0.713	0.159	0.697	0.264	0.517	0.438
	P+DW+OBE	**16.723**	**7.894**	**13.655**	**10.274**	**10.396**	**8.170**
	Allowable (4) (1.5 S_m)	**34.95**	**34.95**	**34.95**	**34.95**	**34.95**	**34.95**
P_L+P_b (Outside)	Press (2)	3.791	5.879	4.686	4.424	1.798	3.965
	DW	3.177	2.339	3.179	2.119	1.788	1.788
	OBE RFE	5.293	3.953	5.297	3.480	2.986	2.986
	Sleeve Load	0.723	0.615	0.725	0.410	0.421	0.421
	P+DW+OBE	**12.985**	**12.786**	**13.887**	**10.433**	**6.992**	**9.159**
	Allowable (4) (1.5 S_m)	**34.95**	**34.95**	**34.95**	**34.95**	**34.95**	**34.95**

Notes:

(1) All units are in ksi.

(2) The P_m and P_L for Pressure load case are scaled to the maximum pressure occurring during the Loss of Feedwater Pump transient, 1,345 psig.

(3) Note that P_L stress results from the ANSYS stress evaluations are conservatively used in place of P_m. The lower allowable values for P_m are used in place of P_L.

(4) Allowable criteria per ASME Code, Section III [7], Figure NB-3221-1 and ASME Code, Section II, Part D [9].

Table 2-4: Service Level A/B Code Evaluation (Inside Location)

		Path 1	Path 2	Path 3	Path 4	Path 6	Path 9
P_L+P_b+Q (Inside)	Press [2]	7.830	6.053	4.833	7.976	4.978	3.096
	DW	3.060	0.620	3.042	0.732	1.814	1.730
	2*OBE RFE	10.239	2.122	10.165	2.604	6.175	5.814
	Therm RFE	13.273	2.703	13.194	3.219	7.897	7.512
	(2) Max. Therm [3]	7.813	31.769	7.964	32.617	30.099	30.877
	Sleeve Load	1.723	0.365	1.690	0.582	1.215	1.051
	P+DW+OBE+THM	**43.939**	**43.633**	**40.887**	**47.730**	**52.178**	**50.080**
	Allowable [5] (3 S_m)	**69.9**	**69.9**	**69.9**	**69.9**	**69.9**	**69.9**
F (Inside)	Press [2]	0.273	0.441	0.716	1.107	0.297	0.173
	DW	0.341	0.289	0.333	0.280	0.206	0.201
	2*OBE RFE	1.136	0.984	1.102	0.942	0.698	0.677
	Therm RFE	1.478	1.259	1.441	1.215	0.895	0.872
	(2) Max. Therm [4]	4.989	7.035	4.996	7.109	12.748	12.788
	Sleeve Load	0.191	0.189	0.176	0.170	0.134	0.124
	P+DW+OBE+THM	**8.408**	**10.198**	**8.764**	**10.822**	**14.977**	**14.835**
P+Q+F (Inside)		50.624	53.466	47.962	57.970	65.939	63.864

Notes:

(1) All units are in ksi.

(2) The P_L for Pressure load case is scaled to the maximum pressure occurring during the Loss of Feedwater Pump transient, 1,345 psig.

(3) Indicates the maximum thermal stress range between the eight transients evaluated. The range is taken as the sum of the two largest membrane plus bending (Q) stress intensity values for two separate transients, for each stress path evaluated.

(4) Indicates the maximum thermal stress range between the eight transients evaluated. The range is taken as the sum of the two largest peak (F) stress intensity values for two separate transients, for each stress path evaluated.

(5) Allowable criteria per ASME Code, Section III [7], Figure NB-3222-1and ASME Code, Section II, Part D [9].

Table 2-5: Service Level A/B Code Evaluation (Outside Location)

		Path 1	Path 2	Path 3	Path 4	Path 6	Path 9
P_L+P_b+Q (Outside)	Press (2)	3.791	5.879	4.686	4.424	1.798	3.965
	DW	3.177	2.339	3.179	2.119	1.788	1.788
	2*OBE RFE	10.586	7.906	10.593	6.961	5.971	5.971
	Therm RFE	13.770	10.168	13.777	9.156	7.752	7.752
	(2) Max. Therm (3)	17.521	24.649	17.740	25.231	29.290	29.973
	Sleeve Load	1.766	1.461	1.769	1.034	1.021	1.022
	P+DW+OBE+THM	**50.612**	**52.402**	**51.745**	**48.925**	**47.621**	**50.470**
	Allowable (5) ($3 S_m$)	**69.9**	**69.9**	**69.9**	**69.9**	**69.9**	**69.9**
F (Outside)	Press (2)	0.758	3.305	1.728	1.651	0.283	0.260
	DW	0.986	1.375	0.970	1.244	0.182	0.176
	2*OBE RFE	3.284	4.650	3.218	4.085	0.613	0.586
	Therm RFE	4.272	5.979	4.201	5.375	0.790	0.761
	(2) Max. Therm(4)	9.342	24.582	9.423	25.030	12.158	12.277
	Sleeve Load	0.556	0.874	0.526	0.619	0.113	0.100
	P+DW+OBE+THM	**19.198**	**40.765**	**20.066**	**38.004**	**14.138**	**14.160**
P+Q+F (Outside)		68.044	91.706	70.042	85.894	60.737	63.609

Notes:

(1) All units are in ksi.

(2) The P_L for Pressure load case is scaled to the maximum pressure occurring during the Loss of Feedwater Pump transient, 1,345 psig.

(3) Indicates the maximum thermal stress range between the eight transients evaluated. The range is taken as the sum of the two largest membrane plus bending (Q) stress intensity values for two separate transients, for each stress path evaluated.

(4) Indicates the maximum thermal stress range between the eight transients evaluated. The range is taken as the sum of the two largest peak (F) stress intensity values for two separate transients, for each stress path evaluated.

(5) Allowable criteria per ASME Code, Section III [7], Figure NB-3222-1and ASME Code, Section II, Part D [9].

Table 2-6: Service Level C/D Code Evaluation

		Path 1	Path 2	Path 3	Path 4	Path 6	Path 9
P_m / P_L (4)	Press (2)	5.743	2.925	4.573	5.496	3.386	3.224
	DW	2.912	1.299	2.890	1.274	1.761	1.705
	SSE RFE (2*OBE) (3)	9.721	4.368	9.623	4.259	5.910	5.666
	Sleeve Load	0.918	0.427	0.894	0.400	0.594	0.534
	P+DW+SSE	**19.294**	**9.018**	**17.979**	**11.429**	**11.652**	**11.128**
	Allowable (4, 5) (Greater of 1.0S_y or 1.2S_m)	**27.96**	**27.96**	**27.96**	**27.96**	**27.96**	**27.96**
P_L+P_b (Inside)	Press (2)	7.830	6.053	4.833	7.976	4.978	3.096
	DW	3.060	0.620	3.042	0.732	1.814	1.730
	SSE RFE (2*OBE) (3)	10.239	2.122	10.165	2.604	6.175	5.814
	Sleeve Load	0.975	0.205	0.956	0.323	0.684	0.594
	P+DW+SSE	**22.104**	**9.000**	**18.996**	**11.635**	**13.651**	**11.234**
	Allowable (5) (Greater of 1.5S_y or 1.8S_m)	**44.55**	**62.25**	**44.55**	**62.25**	**44.55**	**44.55**
P_L+P_b (Outside)	Press (2)	3.791	5.879	4.686	4.424	1.798	3.965
	DW	3.177	2.339	3.179	2.119	1.788	1.788
	SSE RFE (2*OBE) (3)	10.586	7.906	10.593	6.961	5.971	5.971
	Sleeve Load	1.001	0.824	1.003	0.590	0.578	0.579
	P+DW+SSE	**18.555**	**16.948**	**19.461**	**14.094**	**10.136**	**12.302**
	Allowable (5) (Greater of 1.5S_y or 1.8S_m)	**44.55**	**62.25**	**44.55**	**62.25**	**41.94**	**41.94**

Notes:

(1) All units are in ksi.
(2) The P_m and P_L for Pressure load case are scaled to the maximum pressure occurring during the Loss of Feedwater Pump transient, 1,345 psig.
(3) The Service Level C/D seismic load is taken as 2 x OBE seismic.
(4) Note that P_L stress results from the ANSYS stress evaluations are conservatively used in place of P_m. The lower allowable values for P_m are used in place of P_L.
(5) Allowable criteria per ASME Code, Section III [7], Figure NB-3224-1 and Appendix F, and ASME Code, Section II, Part D [9]. Level C values are conservatively used.

Table 2-7: Test Code Evaluation

		Path 1	**Path 2**	**Path 3**	**Path 4**	**Path 6**	**Path 9**
P_m	Press (2)	5.338	2.718	4.250	5.108	3.147	2.996
	DW	2.912	1.299	2.890	1.274	1.761	1.705
	OBE (3)	NA	NA	NA	NA	NA	NA
	Sleeve Load	0.111	0.049	0.110	0.048	0.070	0.067
	P+DW	**8.362**	**4.067**	**7.250**	**6.430**	**4.979**	**4.768**
	Allowable (4) ($0.9S_y$)	**24.8**	**24.8**	**24.8**	**24.8**	**24.8**	**24.8**
P_L+P_b (Inside)	Press (2)	7.277	5.626	4.491	7.413	4.626	2.877
	DW	3.060	0.620	3.042	0.732	1.814	1.730
	OBE (3)	NA	NA	NA	NA	NA	NA
	Sleeve Load	0.116	0.020	0.115	0.026	0.074	0.070
	P+DW	**10.453**	**6.266**	**7.649**	**8.171**	**6.514**	**4.677**
	Allowable (4) ($1.35\ S_y$ (for $P_m \le 0.67S_y$), or, $2.15S_y - 1.2P_m$ (for $0.67S_y < P_m \le 0.9S_y$))	**31.8**	**44.4**	**31.8**	**44.4**	**31.8**	**31.8**
P_L+P_b (Outside)	Press (2)	3.524	5.464	4.355	4.112	1.671	3.685
	DW	3.177	2.339	3.179	2.119	1.788	1.788
	OBE (3)	NA	NA	NA	NA	NA	NA
	Sleeve Load	0.123	0.093	0.123	0.080	0.070	0.070
	P+DW	**6.824**	**7.895**	**7.658**	**6.311**	**3.529**	**5.542**
	Allowable (4) ($1.35\ S_y$ (for $P_m \le 0.67S_y$), or, $2.15S_y - 1.2P_m$ (for $0.67S_y < P_m \le 0.9S_y$))	**29.4**	**29.4**	**29.4**	**29.4**	**29.4**	**29.4**

Notes:

(1) All units are in ksi.
(2) The P_m for Pressure load case are scaled to the Hydrostatic Test pressure of 1,250 psig.
(3) The Test condition does not have any seismic load.
(4) Allowable criteria per ASME Code, Section III [7], Paragraph NB-3226 and ASME Code, Section II, Part D [9].

Table 2-8: Fatigue Usage Evaluation

Path	**Material**	**P+Q+F (ksi)**	**Sa (ksi)**	**E-actual (2) (ksi)**	**E-actual/ E-curve (1)**	**Allowable Cycles**	**Applied Cycles**	**Fatigue Usage**
				Inside Path Location				
1	Alloy 600	50.62	25.31	28.50	1.01	1.42E+06	2254	0.002
2	SA-508	53.47	26.73	24.90	0.83	1.78E+04	2254	0.127
3	Alloy 600	47.96	23.98	28.50	1.01	1.70E+06	2254	0.001
4	SA-508	57.97	28.99	24.90	0.83	1.39E+04	2254	0.162
6	Alloy 182	65.94	32.97	28.50	1.01	3.40E+05	2254	0.007
9	Alloy 182	63.86	31.93	28.50	1.01	4.16E+05	2254	0.005
				Outside Path Location				
1	Alloy 600/52M	68.04	34.02	27.90	0.99	2.56E+05	2254	0.009
2	SA-508/52M	91.71	45.85	24.90	0.83	3.29E+03	2254	0.684
3	Alloy 600/52M	70.04	35.02	27.90	0.99	2.14E+05	2254	0.011
4	SA-508/52M	85.89	42.95	24.90	0.83	4.00E+03	2254	0.563
6	Alloy 52M	60.74	30.37	27.90	0.99	5.24E+05	2254	0.004
9	Alloy 52M	63.61	31.80	27.90	0.99	3.90E+05	2254	0.006

Notes:

(1) Adjustments are made to the curve values to account for differences in elastic modulus (E) between the fatigue curve and the material under consideration. The adjustment factor is: E-actual/E-curve. The E-curve is taken as 30e6 [7, Appendices, Fig. I-9.1] for carbon and low alloy steels; E-curve for austenitic steel (Alloy 82/182/600 and Alloy 52M) is 28.3e6 [7, Appendices, Fig. I-9.2.1]. The lower value from either curve is used for locations with more than one material (i.e. at outside locations such as at the overlay taper.

(2) The E-actual is taken at a conservatively bounding temperature of 650°F.

Table 2-9: Fatigue Usage Using Fatigue Reduction Factor

Path	Material	P+Q (ksi)	P+Q+F (1) (ksi)	Sa (ksi)	E-actual (3) (ksi)	E-actual/ E-curve (2)	Allowable Cycles	Applied Cycles	Fatigue Usage
Inside Path Location									
6	Alloy 182	52.18	93.92	46.96	28.50	1.01	4.65E+04	2254	0.048
9	Alloy 182	50.08	90.14	45.07	28.50	1.01	5.79E+04	2254	0.039
Outside Path Location									
1	Alloy 600/52M	50.61	91.10	45.55	27.90	0.99	5.06E+04	2254	0.045
2	SA-508/52M	52.40	94.32	47.16	24.90	0.83	3.03E+03	2254	0.744
3	Alloy 600/52M	51.74	93.14	46.57	27.90	0.99	4.52E+04	2254	0.050
4	SA-508/52M	48.92	88.06	44.03	24.90	0.83	3.72E+03	2254	0.607

Notes:

(1) P+Q+F stresses are generated by multiplying P+Q by a FSRF of 1.8.

(2) Adjustments are made to the curve values to account for differences in elastic modulus (E) between the fatigue curve and the material under consideration. The adjustment factor is: E-actual/E-curve. The E-curve is taken as 30e6 [7, Appendices, Fig. I-9.1] for carbon and low alloy steels; E-curve for austenitic steel (Alloy 82/182/600 and Alloy 52M) is 28.3e6 [7, Appendices, Fig. I-9.2.1]. The lower value from either curve is used for locations with more than one material (i.e. at outside locations such as at the overlay taper.

(3) The E-actual is taken at a conservatively bounding temperature of 650°F.

Table 2-10: Crack Growth Results

Zero-degree Plane (see Figure 2-2[2])

Flaw Type	Time for Initial Flaw Depth [1] to Reach Overlay
Circumferential Flaw	> 40 years
Axial Flaw	> 40 years

Ninety-degree Plane (see Figure 2-2[3])

Flaw Type	Time for Initial Flaw Depth [1] to Reach Overlay
Circumferential Flaw	> 40 years
Axial Flaw	> 40 years

Notes:

(1) Initial flaw depths = 0.5 inch for the as-found axial flaw and 75% of the original DMW thickness = 1.03 inches for the postulated circumferential flaw.

(2) Evaluated paths for zero-degree plane are Paths 5, 6 and 7.

(3) Evaluated paths for 90-degree plane are Paths 8, 9 and 10.

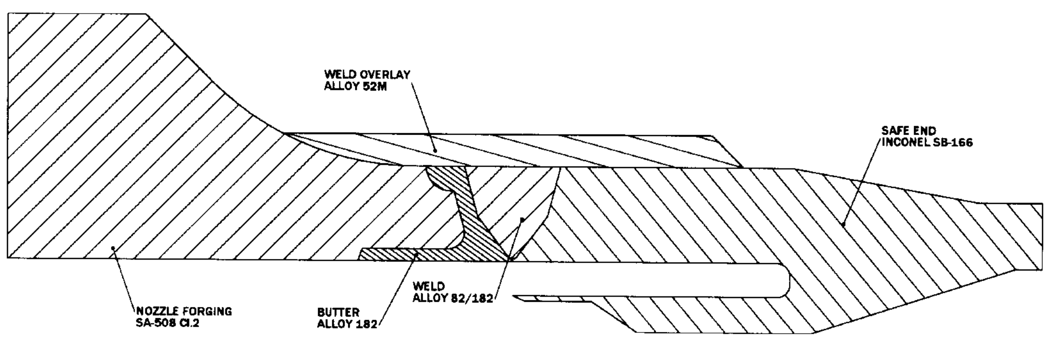
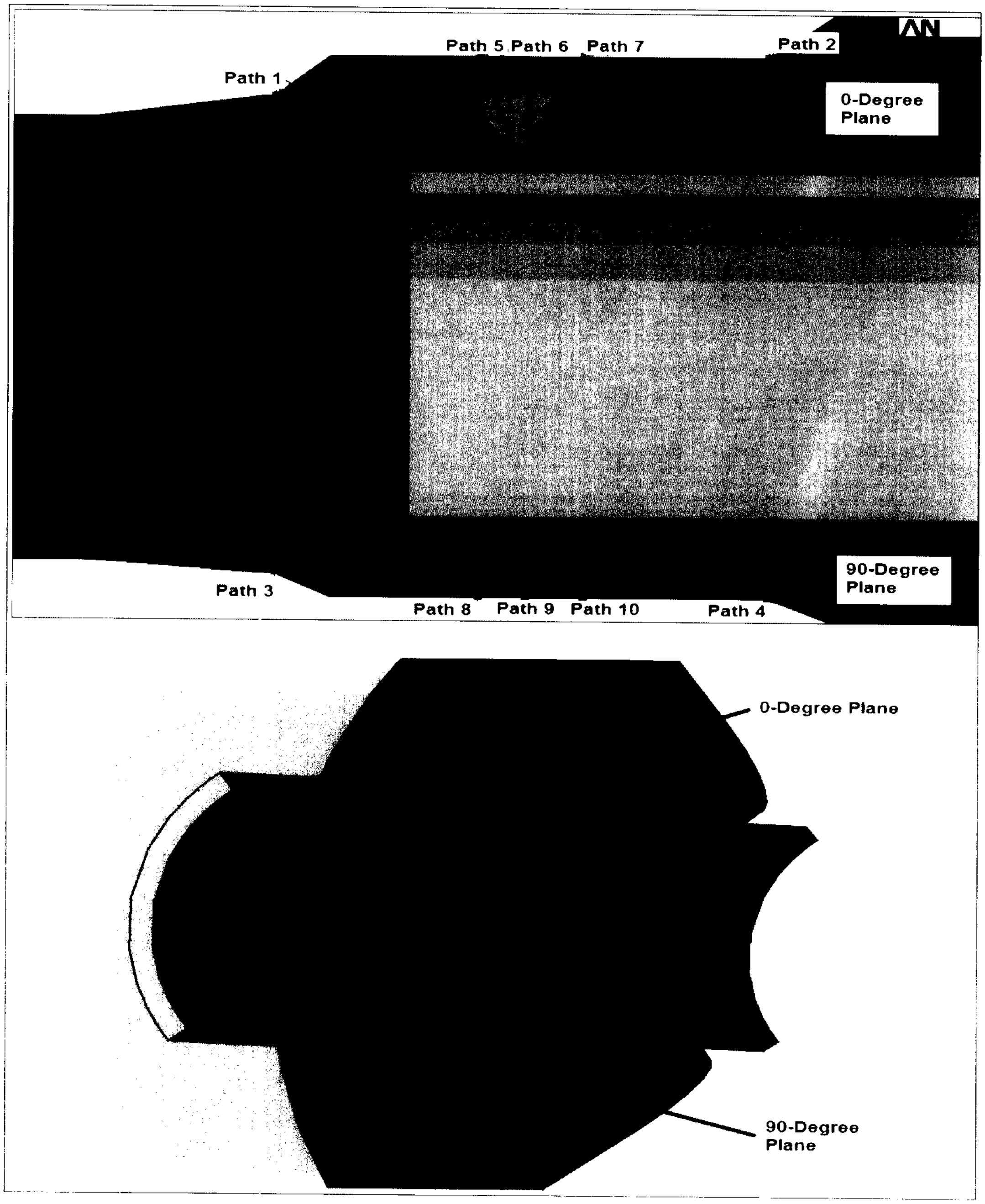


Figure 2-1: Weld Overlay Design Illustration



Note: The cross-sectional planes are 90 degrees out of phase (Paths 1, 2, 5, 6, 7 are on 0-degree plane: Paths 3, 4, 8, 9, 10 are located on the 90-degree plane.

Figure 2-2: Stress Path Definitions

(Note: The inside node is located on the inside face of the nozzle/safe end for all paths.)

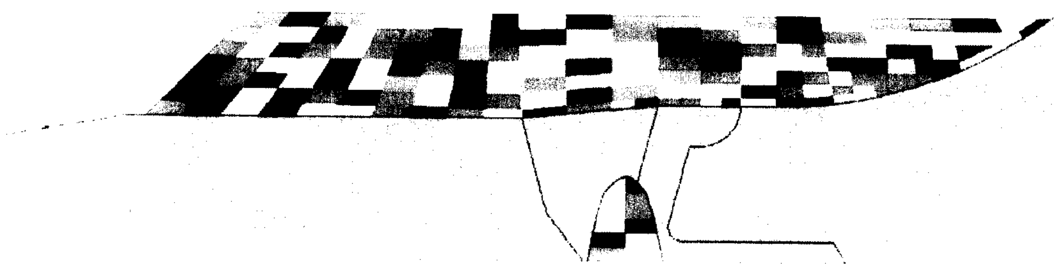


Figure 2-3: As-Modeled Nuggets for ID Weld Repair and WOL

Note: The plot represents the nuggets for all the welding processes involved.

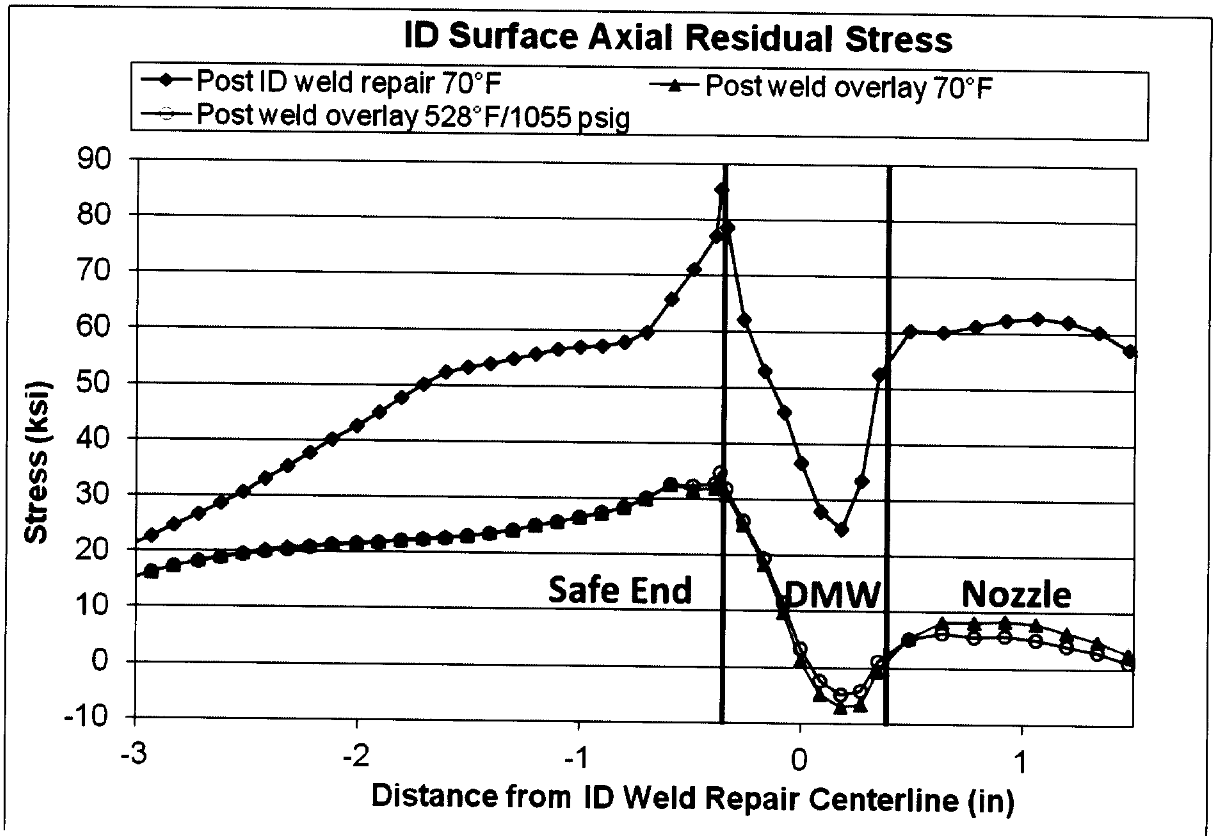


Figure 2-4: ID Surface Axial Residual Stresses

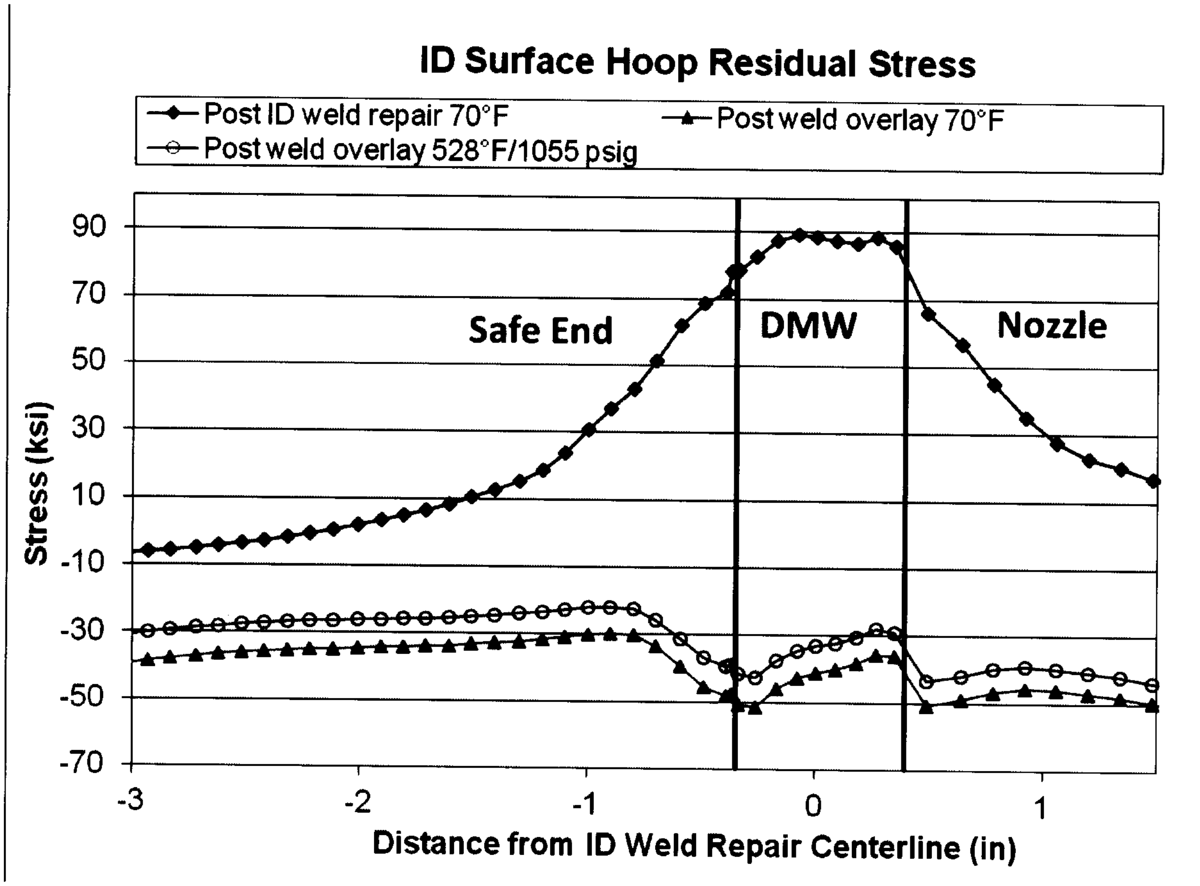


Figure 2-5: ID Surface Hoop Residual Stresses

3.0 *Conclusions*

The design and analysis of the Grand Gulf Nuclear Station RHR/LPCI nozzle-to-safe end weld (N06B-KB) overlay was performed in accordance with requirements of the Relief Request [1], which is based on ASME Code Cases N-504-4 [2] and N-638-4 [3], and ASME Code, Section XI, Nonmandatory Appendix Q [5]. The weld overlay is demonstrated to be a long-term repair and provides mitigation of IGSCC in this weld based on the following:

- In accordance with ASME Code Case N-504-4, structural design of the overlay was performed to meet the requirements of ASME Code, Section XI, IWB-3640 based on an assumed circumferential flaw 100% through-wall, and 360° around the original weld. The resulting full structural weld overlay thus restores the original safety margins of the original weld, with no credit taken for the underlying IGSCC-susceptible material.
- The weld metal used for the overlays is Alloy 52M, which has been shown to be resistant to IGSCC [4], thus providing a IGSCC resistant barrier. Therefore, little if any IGSCC growth is expected to occur in the overlay.
- Nozzle-specific residual stress analyses were performed, after first simulating a severe ID weld repair in the nozzle-to-safe end weld, prior to applying the weld overlay. The post weld overlay residual stresses were shown to result in beneficial compressive or reduced tensile stresses on the inside surface of the components, and well into the thickness of the original DMW, assuring that future IGSCC initiation is reduced and any potential growth into the overlay is highly unlikely.
- Fracture mechanics analyses were performed to determine the amount of future crack growth which would be predicted in the DMW based on the as-found flaw and assuming a circumferential flaw existed that is equal to, or greater than, the thresholds of the NDE techniques used. Both fatigue and IGSCC growth were considered, and found to be acceptable. In this evaluation, the results of the analyses show that, at the susceptible material region, it takes greater than 40 years for the as-found axial flaw and a postulated initial circumferential flaw of 75% of the original base metal thickness at the analyzed section to reach the overlay.
- After completion of the WOL application, diameter measurements of the N-6 nozzle and safe end WOL showed that all WOL dimensions exceeded the design minimums.
- A walkdown of the affected line following the WOL application indicated that all hangers and other supports were within design dimensional tolerances.

Based on the above observations and the fact that similar nozzle-to-safe end weld overlays have been applied to other plants since 1986 with no subsequent problems identified, it is concluded that the GGNS N-6 nozzle dissimilar metal weld (Weld N06B-KB) has received long term mitigation against IGSCC.

4.0 References

1. Grand Gulf Nuclear Station (GGNS) Relief Request ISI-17 Repair Plan for ISI Weld N06B-KB, SI File No. 1200536.204.
2. ASME Boiler and Pressure Vessel Code, Code Case N-504-4, "Alternative Rules for Repair of Class 1, 2 and 3 Austenitic Stainless Steel Piping, Section XI, Division 1."
3. ASME Boiler and Pressure Vessel Code, Code Case N-638-4, "Similar and Dissimilar Metal Welding Using Ambient Temperature Machine GTAW Temper Bead Technique," Section XI, Division 1.
4. Peter L. Andresen, et al., GE Global Research Center, "SCC of High Cr Alloys in BWR Environments," 15th International Conference on Environmental Degradation, TMS (The Minerals, Metals & Materials Society), 2011.
5. ASME Code, Section XI, 2004 Edition with Addenda through 2005, Nonmandatory Appendix Q, "Weld Overlay Repairs of Classes 1, 2, and 3 Austenitic Stainless Steel Piping Weldments."
6. ASME Boiler and Pressure Vessel Code, Section XI, Rules for Inservice Inspection of Nuclear Power Plant Components, 2001 Edition with Addenda through 2003.
7. ASME Boiler and Pressure Vessel Code, Section III, 2001 Edition with Addenda through 2003.
8. ASME Boiler and Pressure Vessel Code, Section III, 1971 Edition with Addenda through Winter 1972 Addenda.
9. ASME Boiler and Pressure Vessel Code, Section II, Part D, Material Properties, 2001 Edition with Addenda through 2003.